Appendix E
Wave Climate Intercomparisons[1]

Wave-climate statistics from the Grays Harbor buoy are accessed in this report to describe the wave climate incident at Willapa Bay (Chapter 5). Wave data from the Long Beach slope array and the Columbia River bar buoy were also analyzed to collaborate climate information obtained from the Grays Harbor buoy. Differences were found between the Grays Harbor and Long Beach wave directional distributions. The purpose of this appendix is to discuss these differences and document why the Grays Harbor data were selected to provide offshore boundary conditions for wave modeling conducted in this project.

The Grays Harbor, Long Beach, and Columbia River bar gauges are described in Chapter 5. For review, the Grays Harbor buoy is located northwest of Willapa Bay (closest gauge to the entrance) in a water depth of 40 m. The Long Beach slope array was southwest of the entrance in a water depth of 10 m. The Columbia River bar buoy is still further southwest in a water depth of 128 m. Table E-1 shows the percent occurrence of wave directions for the Grays Harbor buoy, Long Beach slope array, and the Columbia River bar buoy. In this table, each month is given the appropriate weight (based on the number of days in the month), so large gaps in the data sets do not bias the statistics toward a particular month or season. Also, Grays Harbor data with sampling intervals of 1 hr or less were decimated to 3-hr intervals for consistency. The percent coverage of data for each month is given in Table E-2. The Grays Harbor and Columbia River buoys have similar directional distributions, with the Columbia River buoy recording slightly more waves from the northwest and fewer from the southwest.

The Long Beach array gives a much different distribution with more waves from the west (270-deg band), more from the southwest (247.5-deg band), and fewer from the northwest (292.5-deg band) (Table E-1). These directional differences between the gauges could reverse the direction of estimated longshore sediment transport and change the magnitude of transport. Thus, some explanation of the differences is required to select the most appropriate climate for furnishing offshore boundary conditions to the wave transformation model.

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Table E-1 **Wave Direction Distributions**			
Direction Deg	**Grays Harbor Buoy % occurrence**	**Long Beach Array % occurrence**	**Columbia River Bar Buoy % occurrence**
180.0	0.6	1.8	1.0
202.5	3.8	2.7	4.6
225.0	9.4	8.9	7.6
247.5	12.1	31.4	8.2
270.0	37.8	45.7	33.0
292.5	30.5	8.3	32.0
315.0	5.3	0.4	12.0
337.5	0.1	0.0	1.1
360.0	0.0	0.0	0.4

Table E-2 **Percent Data Coverage by Month**			
Month	**Grays Harbor Buoy % coverage**	**Long Beach Slope Array % coverage**	**Columbia River Bar Buoy % coverage**
Jan	8.7	8.3	9.8
Feb	8.4	7.7	3.1
Mar	8.6	8.4	3.4
Apr	5.9	8.1	3.3
May	7.4	8.0	9.6
Jun	7.7	7.0	10.0
Jul	9.4	5.7	10.9
Aug	8.9	8.3	11.0
Sep	9.7	10.0	10.3
Oct	10.1	10.8	10.4
Nov	7.3	9.0	10.0
Dec	7.9	8.6	8.2

Figure E-1 compares a time-history of zero-moment wave height measured at the Grays Harbor and Long Beach gauges for March 1995 (one of the few coincident months of data). The heights agree well for this month. For some events, the Long Beach heights are higher, probably produced by local wave shoaling in the shallower water. For the largest wave height in the month, the Grays Harbor buoy wave height is higher, probably because of depth-limited breaking at the Long Beach gauge. Figure E-2 compares significant wave direction for the same month. The directions for the two gauges show similar trends, but there are significant differences. First, the Grays Harbor directions

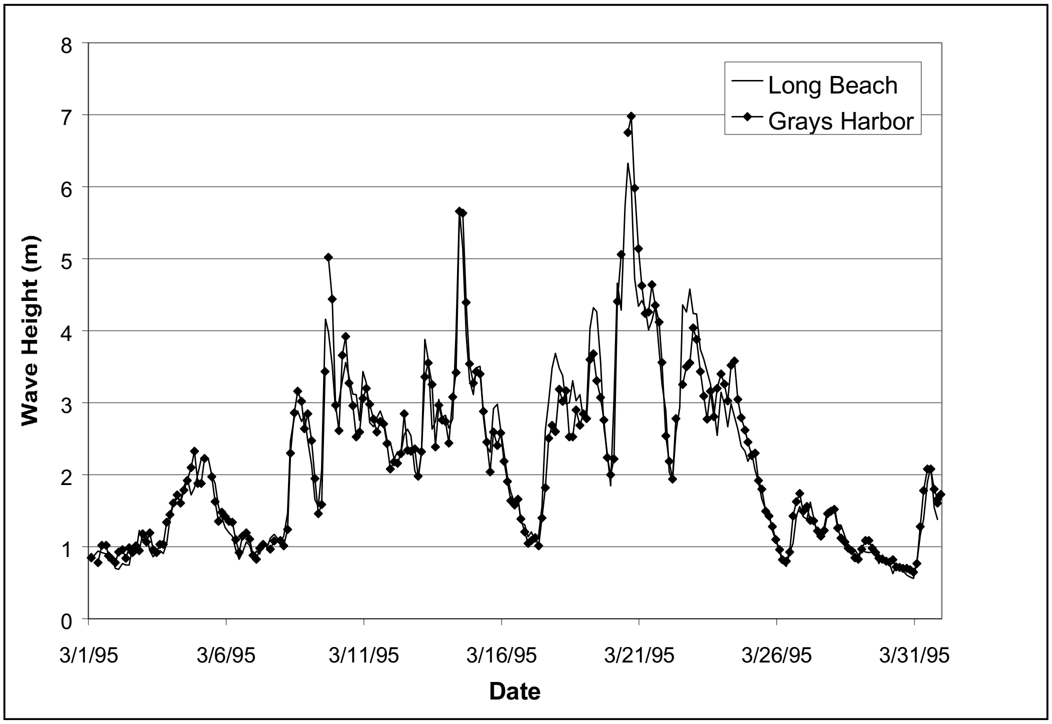

Figure E-1. March 1995 wave heights for Long Beach slope array and Grays Harbor buoy

are generally more oblique (further from 270 deg). Reduced obliqueness at the Long Beach gauge is caused by more refraction (wave aligning with the normal to shore, 270 deg). Second, the Long Beach directions oscillate 5 to 25 deg with the tide (most obvious in the last third of the record), caused by refraction over the tide-varying water depth. The tidal variation in direction is strongest at Long Beach because the tide range is a large fraction of the water depth (on the order of one-third the depth).

Figure E-3 shows a scatter plot of measured directions for March 1995 for the Grays Harbor and Long Beach gauges. This shows again the reduced spread in direction at the Long Beach gauge caused by refraction. The mean wave direction for March 1995 was 256.8 deg at the Grays Harbor gauge and 253.2 deg at the Long Beach gauge. Figures E-2 and E-3 support the increased occurrence of waves in the 270-deg band at Long Beach (45.3 percent at Long Beach versus 37.8 at Grays Harbor), but they do not explain why the Long Beach array distribution is skewed to the south and that of the buoy is skewed to the north. The local bottom contour and shoreline orientation at both Grays Harbor and Long Beach are approximately north-south. Thus, local refraction does not explain the difference in distribution skewness. To better understand the difference in directional distribution, the monthly variation in direction is investigated in the next paragraph.

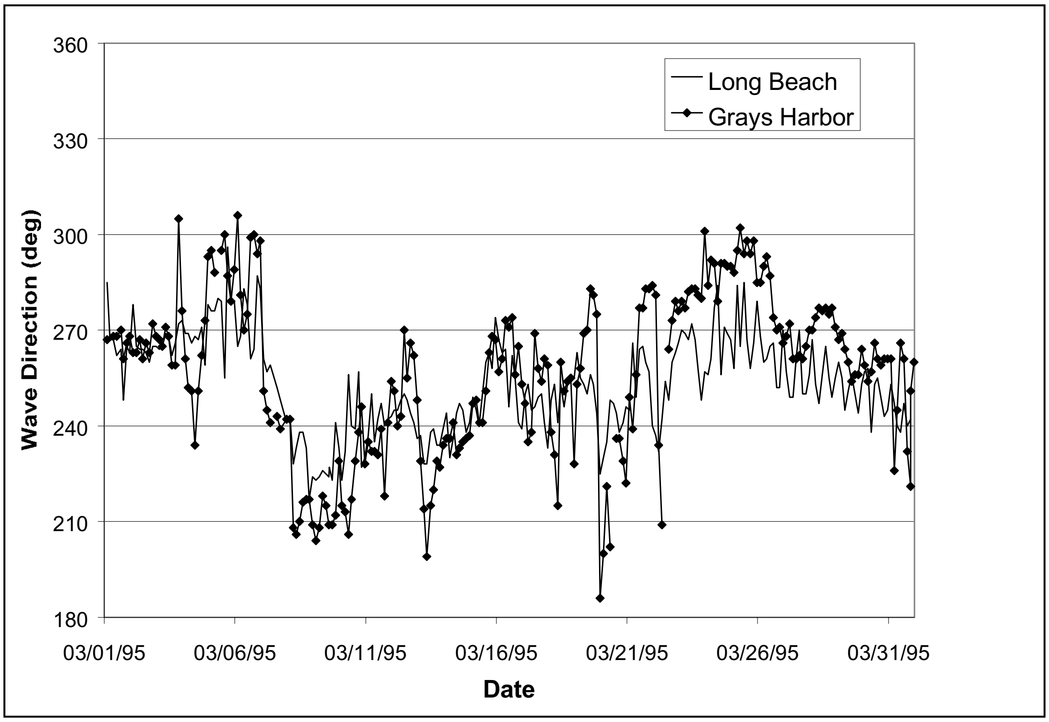

Figure E-2. March 1995 wave directions for Long Beach slope array and Grays Harbor buoy

The monthly-averaged wave directions for Grays Harbor and Long Beach are given in Figures E-4 and E-5, respectively. Each year is plotted separately to show year-to-year variability and anomalies in the data. The Grays Harbor buoy data exhibit a strong trend of southwesterly mean direction from November to April and northwesterly direction from May to October, with a total range of 240 to 300 deg. The Long Beach gauge data show much less seasonal variation in mean direction (range of 240 to 280 deg). In May through July, the monthly mean wave directions at Long Beach are 10 to 20 deg less than at Grays Harbor. During the other months, the mean directions are similar at the two gauges. Figure E-6 shows coincident months of mean wave directions for Grays Harbor and Columbia River (the Long Beach gauge stopped operating by the time the Columbia River buoy became directional). This figure indicates good seasonal agreement in wave direction between Grays Harbor and Columbia River. This agreement supports the accuracy of the Grays Harbor measurements and brings into question the measured directions by the Long Beach gauge.

Because of the good direction agreement between Grays Harbor and Columbia River buoys, which bracket the Willapa entrance and the Long Beach gauge position, it is concluded that the Grays Harbor gauge is most representative of the wave climate at Willapa Bay. The difference in summer wave angles at the Long Beach gauge may be related to limitations of the bottom-mounted pressure gauge in resolving wave direction for the shorter-period summer waves in 10-m water depth. In addition to the apparent problems in resolving the direction of summer (shorter period) waves at Long Beach, the gauge has a compressed directional variation because of refraction, increased variance in direction introduced by the tide, and depth limitations for maximum wave height. These factors make the Grays Harbor buoy the appropriate source of wave climate information for the Willapa entrance.

People with local experience navigating the Willapa entrance have stated that waves from the southwest are significant and suggested that they may be underrepresented in the Grays Harbor climate. This perception of under-representation may owe to the fact that although the waves south of west comprise only 26 percent of the distribution, these waves include the large winter storm waves that can limit navigation and are the most visible.

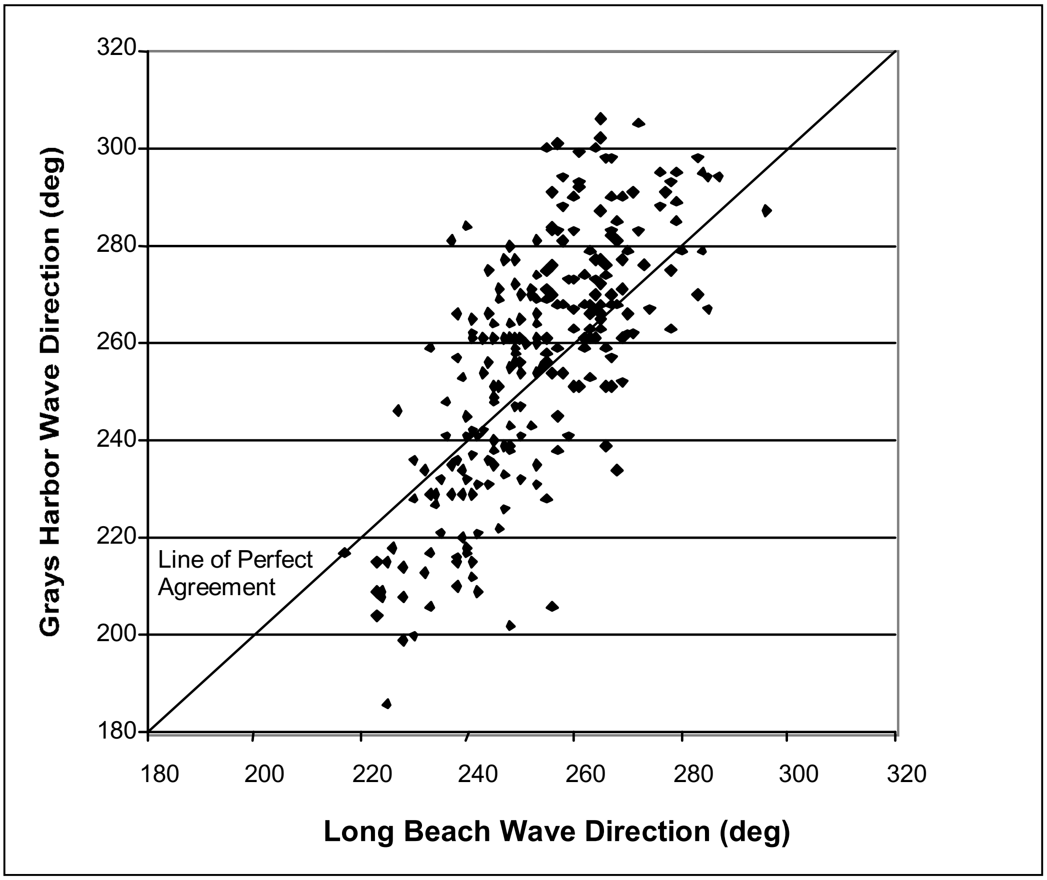

Figure E-3. Scatter plot of Grays Harbor and Long Beach wave directions for March 1995

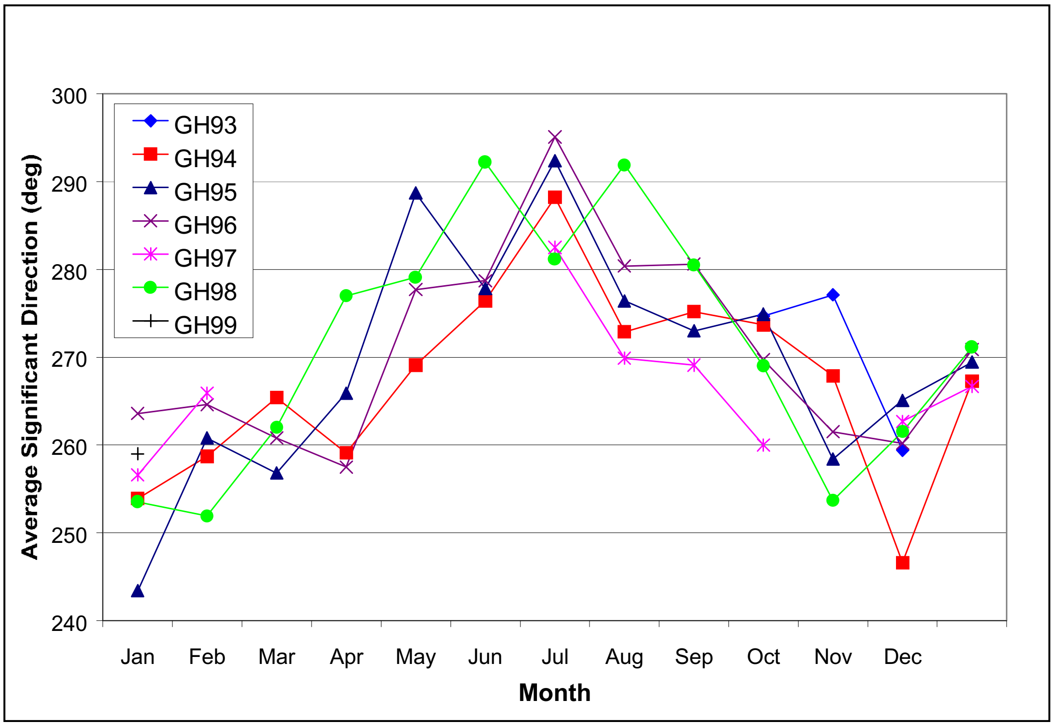

Figure E-4. Monthly average wave directions for Grays Harbor buoy

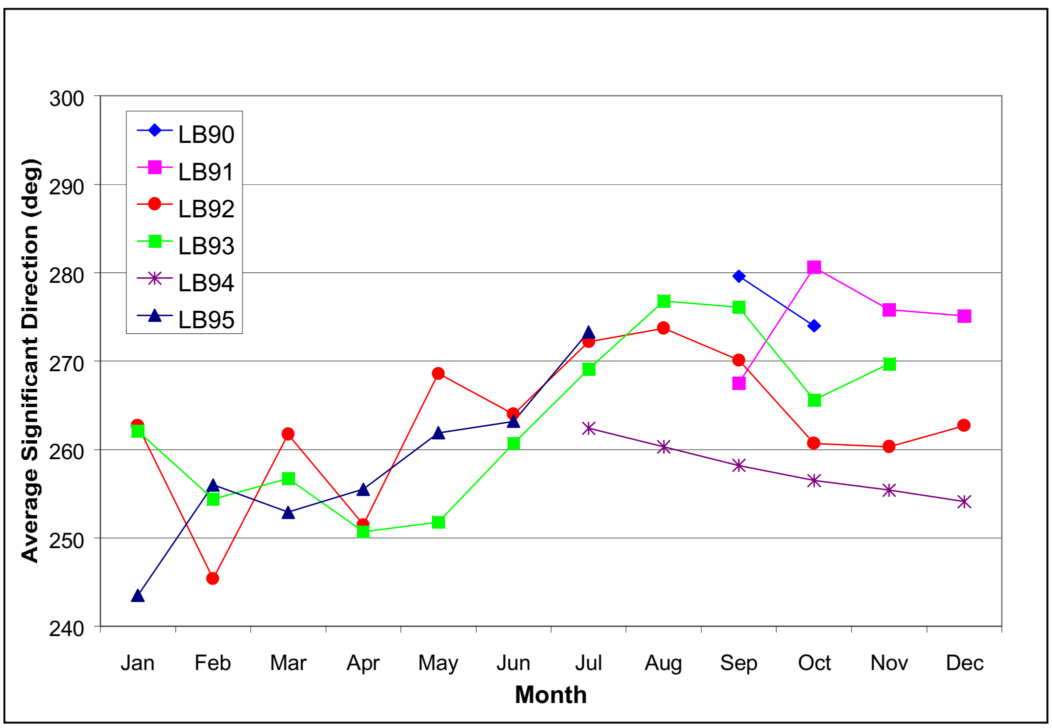

Figure E-5. Monthly average wave directions for Long Beach slope array

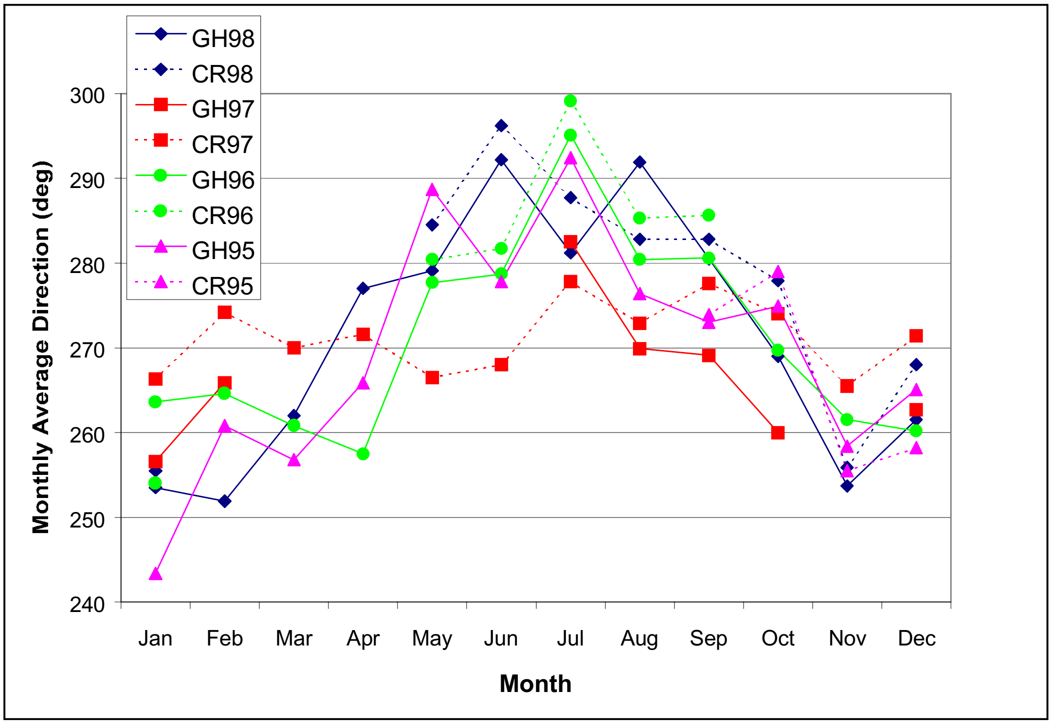

Figure E-6. Monthly average wave directions for coincident Grays Harbor buoy and Columbia River bar buoy measurements